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**POTENTIAL MEANS OF SUPPORT FOR MATERIALS  
PROCESSING IN SPACE -- A HISTORY OF GOVERNMENT  
SUPPORT FOR NEW TECHNOLOGY**

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16. ABSTRACT  A debate has been going on in government on the subject of "Should government funds be spent on early research and high-risk development of new technology?" Opponents claim that if a product is worth the effort, then private enterprise will invest in it. Proponents claim that we are all beneficiaries of new technology. Today, the answer impinges on doing materials processing and other commercial endeavors in space. Here, we discuss past experience in nurturing new ideas, and find two themes. In the first, the military initiates development of a given technology for national defense, and the marketplace makes use of the technology. In the second, the government supports large systems developments when the task is too large or risky for entrepreneurs, yet is clearly in the best interest of the nation. NASA has completed advanced research to identify areas of interest. Examples of commercial opportunities are the McDonnell-Douglas Corporation purification process for pharmaceutical products and the Microgravity Research Associates process for growing gallium arsenide crystals in space. Additional technology developments are in the pipeline.			
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## TECHNICAL MEMORANDUM

### POTENTIAL MEANS OF SUPPORT FOR MATERIALS PROCESSING IN SPACE-- A HISTORY OF GOVERNMENT SUPPORT FOR NEW TECHNOLOGY

#### I. INTRODUCTION

A debate centered on the question: "Should taxpayers money be spent on high-risk development of new technology?" continues to be argued in the halls of the United States Government. The arguments are currently focused on the National Aeronautics and Space Administration (NASA); however, they are of vital importance to the Departments of Commerce, Defense, and Energy, several regulatory agencies, and both houses of the Congress and their subcommittees.

The question spawns many detailed queries, particularly in a time of governmental deficits and strict budgetary scrutiny. First, is the research necessary and can it be justified? Which projects should be selected and on what basis? Who should judge and what are their claims to expertise and objectivity? Second, if the Federal Government should not support new developments, then who should, and are they willing to take the risk? It is argued that if a project is worth doing, then those who will benefit should pay the cost. That sounds fair and logical, but what if the identified future beneficiaries cannot afford the cost? What if the idea is too new to identify future beneficiaries? Last, if new technology is not pursued, what will be the consequence? Will the United States continue to grow and compete in the world economy?

Several concerns follow the initiation of government technology. How and at what point of development should the project be turned over to industry for commercial exploitation? How will patents and other intellectual rights be controlled? And finally, how should the government support the development? Federal research and development contracts are direct methods of support, but more often indirect support has been effective. Tax writeoffs for all research expenses (including the failures), land grants, favorable legal treatment, federal franchises, and regulations restraining trade to the advantage of the risk-takers -- examples of these governmental supports to new technology will be given in this report.

Foreign experience, especially in central Europe and Japan, shows that government can set up a laboratory cooperating with an entire industry involving many competitors. Of course, they are not concerned with antitrust laws restraining cooperation between competitors. Many Americans, dedicated to capitalistic free enterprise and the operation of a free market, will opt for private research to do the whole job. But the question raised here is not capitalism versus socialism or even conservatism versus liberalism in government and economics. It has to do with the competition of the United States versus other nations in a world economy as pertains to jobs, the standard of living, and national security.

We will examine history to see in what way new projects were supported in their time and how they supported the growth of the nation. We will look at yesterday's new technology, mostly in the field of transportation, such as railroads, aircraft, and spacecraft, in an attempt to apply the past to current questions in research and development for NASA and other organizations.

Two overriding themes occur throughout this history of government support to high technology. In the first, the military initiates development of certain technologies because the national defense needs can be seen, and, thus, established

earlier than those of the marketplace. The Royal Observatory, jet aircraft, and nuclear reactors are examples of this support.

The second theme concerns government support of large systems development when the task is too large or risky for entrepreneurs, yet is in the best interest of the United States. Examples include the construction of the canals and the railroads as well as landing on the moon.

## II. PORTUGUESE AND ENGLISH EXPERIENCE LEADING TO THE FIRST PROJECT-ORIENTED NATIONAL RESEARCH LABORATORIES

In 1385, the Portuguese defeated the Castilians in the Battle of Aljubarrota and initiated a golden era of exploration. The House of Aviz under King John and Queen Philippa led the way in geographical expansion largely because of their son, Prince Henry. "The Navigator" preferred to be a researcher rather than a soldier [1]. Prince Henry was motivated by strong nationalism, curiosity, and commercial zeal, but not by the military arts. Well educated and knowledgeable of the best scientific techniques, he was a leader who could inspire others to extraordinary achievements within the confines of government. He joined a religious order, as did most academics of his day, and founded a research center for marine exploration at Sagres near Cape St. Vincent, the southeastern point of Portugal.

Henry gathered all writings, maps, and drawings he could find into his specialized library, and enticed international experts to join his research team, thereby setting a precedent followed to this day. Some of the experts included Arab Muslims, who made excellent sails, and Jewish astronomers who had collected the best maps at that time. Although Henry died in 1460, Vasco de Gama and Christopher Columbus later spent time at Sagres studying his findings before embarking on their great journeys. Their successes are tributes to Prince Henry's developments. What were those developments, what did they cost, and what were they worth?

Henry had unknowingly founded the first systematic, interdisciplinary applied science project. He had specific goals to foster seafaring travel: precise navigation, long-term storage of food and water, stability of ship hulls, and stronger sails and rigging. His group developed the science of navigation using an improved sextant to measure the local angle to the sun or a star. Researchers at Sagres knew that the Earth was a sphere 75 years before Columbus sailed to the West Indies. By measuring the radius and circumference of the Earth, the Portuguese were able to navigate great distances when no other navies could do so. Barrels were built to contain fresh water longer, allowing lengthy journeys. They learned to twist rope and to stiffen sails with battens. The "Caravelle" hull design was developed, creating the fastest ship of its day.

Because of Prince Henry's improvements in ships and naval equipment, Portuguese sailors reached Madeira, the Azores, and the coast of Morocco. One hundred years later they discovered Brazil. Henry was the first to provide technological advantages of research to a state so that its influence and power could be extended far beyond its borders. By accomplishing simple, short-term goals and employing the results into a seafaring system, he greatly expanded human horizons. Five hundred years later, Werner von Braun brought the same visionary genius to space exploration that "The Navigator" brought to maritime exploration. They both used the best technology available to do new things, and worked within the framework of available governmental resources.

What was the cost of this practical laboratory and the essential information it produced? No exact budgets exist today, but it is varied from 10 to 50 man-years during its existence, or an accumulation of 4,500 man-years. Many modern project managers would be exceedingly proud of so many accomplishments with such an effort.

The Sagres Laboratory lasted 158 years until it was destroyed by the Englishman, Sir Francis Drake. It met its demise, to some degree, because the Portuguese did not understand or appreciate its importance. Domination of sea exploration and trade shifted to Spain, who ultimately lost its lead to England. England's expertise in seafaring technology was due primarily to the English Royal Observatory at Greenwich.

The first preplanned research laboratory was constructed in 1675 and given specific scientific goals. King Charles II recognized its importance to his Navy and established the Royal Society to gain control of the laboratory. Sir Isaac Newton, chairman of the Society in 1690, became involved in its research programs. Queen Anne ordered the Observatory to make annual reports to the Royal Society and to the Admiralty. Under the direction of Edmund Hale, the Society issued the first request for proposals to improve navigation by devising a system to accurately measure longitude.

While it was known that longitude could be measured by the difference in time between the local noon and the noon of Greenwich Mean Time on a clock, clocks were notoriously unreliable onboard ship. Pendulum clocks would not work on a rolling ship at sea, and spring-driven clocks were temperature sensitive and susceptible to salt corrosion. The "contest" was won by a Mr. Harrison, who designed a clock with a jeweled bearing which reduced friction and a bimetallic spring to compensate for temperature changes. To test the clocks, the first known environmental chamber was constructed by the Observatory. In addition, Captain Cooke evaluated various clocks on his celebrated journey to the South Pacific.

Because of the continued direct research projects of the Observatory, navigation on long ocean voyages became more precise and practical. The contributions of the Royal Observatory to nautical science proved successful to the extent that a counterpart, the United States Naval Observatory in Washington, DC, was established by President John Adams in 1779 to conduct like science for the U.S. Hence, the institution of government research with specific goals and a multidisciplinary staff came to America.

### III. THE ERIE CANAL

The Erie Canal was the most ambitious engineering undertaking of its time. It involved new methods, and therefore technological risks, in surveying accuracy and lock hardware [2]. The canal channeled water from Lake Erie, 570 feet above sea level, near Buffalo, New York, through 363 miles of navigable canal and 83 locks to the Mohawk and Hudson Rivers, essentially at sea level, near Troy, New York. Dug 28 feet wide at the bottom, 42 feet wide at the top, and 4 feet deep, it carried barges which were 80 feet in length and 15 feet in width, with a 3.5-foot draft -- barges which were pulled by horses.

Federal financing was sought by DeWitt Clinton in 1812, but he was bitterly opposed by cities in economic competition with New York. Clinton presented convincing arguments to the State of New York to obtain government funding. The state

and what private financiers could not: accept the enormous risk and initial cost. After being in the planning stage for many years, construction began in 1817, paid for by the State of New York, at a cost of \$7,145,789. The Erie Canal opened in 1825 and brought \$121,461,891 directly to the state until 1882, when tolls were abolished.

The port cities of Philadelphia and Baltimore suffered economically as a result of the canal which provided a freight route around the Appalachian Mountains. New York City prospered greatly and never lost its advantage as the primary port of entry. Prior to opening of the canal, freight traveled by boat from the Great Lakes up the St. Lawrence River, approximately 2,000 miles, or down the Ohio and Mississippi Rivers, approximately 3,000 miles, to the east coast at considerable expense and loss of time. By 1835, a ton of freight could be hauled from Lake Erie to the Hudson River in 23 days at a cost of \$4 per ton. Food stuffs and raw materials moved from the Mid-west prairies of the Ohio territory to the east coast, and manufactured goods migrated westward.

Between 1825 and 1829, other canals received subsidies from the Federal Government. They included the Louisville and Portland Canal (\$235,000), Chesapeake and Ohio Canal (\$1 million), and the Chesapeake and Delaware Canal (\$225,000), as examples.

The new transportation system returned the original investment many times over by encouraging commerce, which resulted in subsequent canals and waterways, that also prospered. The advent of the railways, offering a higher technology, greater convenience, and lesser expense, finally overshadowed canals as a means of transportation, toward the end of the century.

#### IV. RAILROADS

When we speak of high technology today, we tend to overlook technical advances and incentives which enabled an established system, such as the railroads, to work so well. The development of rolling stock hardware and the expansion of track and facilities progressed slowly in the early 1800's with a minimum of government help. The explosive growth of the railways came at the end of the Civil War and, with an influx of government aid, lasted into the 1890's. Trackage increased from 35,000 miles, mostly east of the Mississippi River, to about 200,000 miles, including five separate transcontinental lines. The "Wild West" opened to immigration and settlement, to agriculture in the wheat and corn belts, and to the heavy industries of iron and steel [1].

This great expansion of the American Republic, which gave hope and opportunity to millions, was based on the development of the coal-fired steam boiler, the steam-piston slide valve, the Westinghouse airbrake, and the safety coupler for the rolling stock. Much was learned about elastic foundations, track support, and bridge tressels, fortifying the rail-bed for heavy loads and long life. These developments, brought about by private enterprise over a period of 150 years, made the steam engine efficient and contributed to the internal combustion engine of the twentieth century.

The steam engine slide valve had only two moving parts, the piston and valve. Its genesis was the pop-up valve on Newcomen's primitive steam engine in 1712. In 1776, James Watt provided several innovations with more elaborate valving, but it

remained a single action pump, a closed cylinder with inlet and exhaust valves. In 1785, Watt finally arrived at a four-function valve, with inlet and exhaust at each end of the cylinder. It became more efficient when Murdock, of the English engine company of Boulton and Watt, gathered all the valve functions into a single slide to open and shut the ports at each end of the piston. Murray, in 1802, and later Corliss, improved the valving by bringing the ports closer together.

The Westinghouse airbrake was the first step beyond the mechanical friction-brake and a major step in the safety of railroading. Invented in 1869, it absorbed energy by compressing air into a cylinder and led to the quick-acting, incompressible fluid brake used in today's automobile. The safety coupler was an automatic snap-action connector, which replaced a man-tended latch. Before it was devised, many men were hurt and killed coupling and decoupling heavy railroad cars. These improvements came about slowly through private initiative. After 1865, development, particularly of safety and comfort items, came at a faster pace.

The Pacific Railway Act was signed into law in July 1862, but construction did not begin until after the war in 1865. The law initially called for construction of one transcontinental railroad to be built by two corporations in competition. The Union Pacific, led by General Grenville Dodge, was to go 900 miles westward, starting in Omaha, Nebraska, crossing the Rocky Mountains. The Central Pacific, led by Leland Stanford, was built 600 miles eastward from Sacramento, California, over the terrain of the Sierra Mountains and the Nevada deserts. Obstacles to construction seemed inconquerable. They bridged deep valleys and flooded mountain streams; they withstood deep snows in the mountains and heat in the deserts; they planned logistics for long supply lines for every conceivable item. The Union Pacific met the Central Pacific at Promontory Point in the Great Salt Basin 60 miles north of Salt Lake City, Utah, on May 10, 1869.

The law made the two companies into competitors for government aid, which was parcelled out based on the miles of track laid. It provided a land grant of up to 20 miles on either side of the completed track and loans of up to \$48,000 per mile of track. A great motivator, it gave 20,000 men the incentive to lay up to 8 miles of track per day.

Congress chartered three other transcontinental railroads with land grants: the Northern Pacific from Lake Superior, across the Dakotas, Wyoming, Idaho, and Oregon to Portland; the Southern Pacific from New Orleans, across Texas, New Mexico, Arizona and up to the San Joaquin Valley to San Francisco; the Santa Fe, from Atchison, Kansas, to Santa Fe, New Mexico, across Arizona just south of the Grand Canyon, across the Mojave Desert to San Bernadino and San Diego, California. The other transcontinental railroad was the Great Northern, the brainchild of another charismatic, hard-driving leader, James J. Hill. He started on his own at the small town of Minneapolis, Minnesota, across North Dakota, Montana, to Tacoma, Washington. The last of the five, it was completed in 1893.

For several decades, railroading was the biggest business around, east or west, and it made customer development its business. There was healthy competition to develop whole cities and their commerce, along with some fierce financial battles.

The three most northwestern states, Washington, Oregon, and Idaho, increased in population from 282,000 to over 2,000,000 in 30 years. California, which had only 500,000 people in 1870, became the most populous state in 1925. Trade with the

western states was profitable to the eastern railroads, shipping ports, and factories. After all, a lot of steel went into those engines and rails. The great Baldwin Locomotive Works in Philadelphia, Pennsylvania, became the world leader in new and bigger engines, taking the lead from the English. The steel mills of the East, such as in Pittsburgh, enjoyed prosperous times, and Birmingham, Alabama, grew from almost nothing with the discovery of plentiful coal and limestone deposits and a rich, iron-ore seam.

In agriculture, the greatest crop was no longer "King Cotton" in the South, but "King-Wheat" in the Mid-west. New strains of wheat, improvements in farm machinery, dry-farming techniques, milling processes, and grain-elevator combines flourished. Mid-America was recognized as the breadbasket of the world. This could not have happened without enthusiasm and pressure from the railroads. The immigrants from the old world built the railroads, cleared the farmlands, and populated the country. It was the Irish, Germans, and Italians in the East. The Chinese are remembered as the primary laborers of the Central Pacific Railroad and others in the West. Many small national and ethnic groups added their part to the great expansion.

The Federal Government's role was vitally important to the great expansion. The idea of railroads had been around for 150 years, but not one entrepreneur had the resources to take the risk and put the whole system together on the vast, long-distance scale required. Overall, the Federal Government gave the railroads 131,350,534 acres in land grants. Various states added another 48,883,373 acres. The Desert Land, Timber, Stone, and Forest Lien Acts allowed the railroads to exchange barren desert land for timbered, mineral-rich land. These rich subsidies have been attacked and vilified as "gifts to the rich," and critics have named the well-endowed directors of the railroads, "robber barons." These were government investments in the future of the nation which repaid the government handsomely. Loans given directly to the Union Pacific and Central Pacific Railroads in the amount of \$64,000,000 were repaid within a few years with interest totaling over \$100,000,000. The railroads carried military personnel, supplies, and mail at greatly reduced rates which alone repaid the debt on the land by nearly 10 times the initial cost. The area was opened, land developed, and new cities built. Taxes on these improvements to states totalled many times the investment.

Who can begin to estimate what the West has been worth in supporting life, providing opportunity, and offering hope for the future, to a large segment of humankind? The American public was extremely happy and understanding with the progress made in spite of the cries of abuse on the political scene. Until the automobile and airplane, the West really had no alternate means of transportation. The great historian, Admiral Samuel Elliot Morrison, said: "Short of government construction and operation - something unimaginable to America - this was probably the only way to get the western railroads built." The railroads provided an example of slow, private development of the technology -- but fast, government-subsidized development of the large system where private enterprise could not afford the risks or provide the resources.

#### V. NATIONAL ADVISORY COMMITTEE ON AERONAUTICS

Although the Wright brothers designed and flew the first airplane in America in 1903, it was the Europeans who made technological progress through the end of World War I. American companies tried during this time but never produced a fighter plane to compare with the French Spad or the German Fokker-Wulfe. When World War I

began, the U.S. had 23 airplanes, France 1400, Germany 1000, Russia 800, and England 400.

The National Advisory Committee for Aeronautics ("National" was added at the first meeting) (NACA) was founded in 1915 as an amendment to the Naval Appropriations Act to overcome this deficiency [3]. Twelve members were appointed by the President of the United States and served without financial compensation. They were charged to "supervise and direct the scientific study of the problems of flight, with a view to their practical solution, and to determine the problems which should be experimentally attacked, and to discuss their solution and their application to practical questions." In 1917, NACA began research at Langley Field on the peninsula between the James and York Rivers in southern Virginia. At Langley, theoretical experimental research was conducted in subsonic wind tunnels. Nearly all efficient wing designs, airfoil cross-sections, wing plans, sweep angles, control surfaces such as flaps and ailerons, and antiroll and antispin designs came from NACA in-house research. This was accomplished in 25 years with a budget of only \$38 million, which paid for the salaries of approximately 650 experts and the assets in laboratories and wind tunnels available to this nation at the start of World War II.

NACA's research in the 1930's contributed mightily to the World War II effort. The superior flying quality of the P-38 to P-51 fighters and the B-17 to B-24 bombers, which American pilots flew throughout World War II, was based on NACA development and design criteria. In 1941, Ames Aeronautical Laboratory was set up at Moffet Field, south of San Francisco, California; and in 1942, the Lewis Flight Propulsion Laboratory began operations in Cleveland, Ohio. Post-war research centered on jet and rocket engines: developing supersonic speeds, reaching higher altitudes, and improving thrust-to-weight ratios. A series of experimental aircraft, the X-1 to the X-15, set record after record. Fundamental research ensued leading to the jet and space ages. The cost of this research from 1942 to 1958 was \$900 million. It must be stated that this must rank high in economic returns per dollar of government-supported technology, considering the income of the U.S. aircraft and aerospace industry, which is still the world's leader.

## VI. COMMERCIAL JET TRANSPORT AIRCRAFT

Many remember the pleasant transition from propeller to jet aircraft travel based on their first trip on a Boeing 707, which, when compared to the earlier travels, was fast, smooth, and quiet. They may not have realized that the United States Air Force paid for the development of the prototype of the 707, the KC-135, which paved the way. The 707 was a simplified version of the KC-135 built for commercial passenger transportation. The KC-135-80 prototype first flew July 15, 1954. It was a new and wonderful airplane that flew at a speed of 627 mph -- twice the speed of its propeller competition. The turboprops flew at 350 mph, and the piston prop flew at 260 mph with a high level of noise and vibration, about 90 db. The 707, like its KC-135 older brother, was 144 feet long, with a 130-foot wing span swept back at 35 degrees, which made it look fast for its day. Passenger capacity was 189, a big step from its immediate predecessors of 90 passengers.

Developed with the Air Force KC-135 was the turbofan engine, the Pratt and Whitney JT3C-6, which gave 13,500 pounds of thrust. It powered both the KC-135 and the 707, employing four power plants slung under the wings. These engines were the engineering marvel of the day, with the turbine spinning up to 30,000 rpm and

achieving temperatures over 1000°F in the combustion chamber. The old propeller drivers seldom exceeded 3,000 rpm. The civilian version, 707-120, first flew on December 20, 1957, 2 1/2 years after the Boeing Company obtained clearance from the Air Force to build the 707 commercial derivative of the KC-135. A total of 834 Boeing 707's and subsequent 720's were built, providing one of the largest production runs for modern aircraft. This giant step into the jet age is an example of necessary military technology paying for the enabling technology of a large and profitable commercial market.

## VII. NUCLEAR REACTORS: FROM BOMBS TO PROPULSION TO ELECTRICITY

In Berlin in 1938, Otto Hahn and Fritz Strassman proved that the uranium atom would split when bombarded with neutrons. Thus began the atomic era. Later that year in Paris, Frederic Joliot-Curie showed that the uranium atom would release more than 1 neutron and cause an energy-releasing chain reaction when split. He wrote a patent on a bomb and sketched out a workable, controllable reactor [4].

Throughout the United States, France, Germany, and Russia, physicists pursued their nuclear experiments and became respectable members of war cabinets. In America, Leo Szilard, a Hungarian physicist who escaped from Hitler's persecution, was concerned about the outcome. He teamed up with Enrico Fermi to confirm Joliot-Curie's experiment. Realizing that the world was changed forever, Szilard persuaded Einstein to write his famous warning to President Franklin D. Roosevelt.

The advent of nuclear reactors occurred December 2, 1942, when Enrico Fermi built an atomic reactor in a squash court under the stands of a football stadium at the University of Chicago, producing the first controlled, sustained nuclear reaction. In 1942, the Manhattan Project was organized by General Leslie Groves to produce the atomic bomb. The project required \$2 billion and 100,000 men and women over a period of 3 years. It left an important legacy of \$1.4 billion in capital equipment, nuclear plants, and laboratories primarily at Hanford, Washington, on the Columbia River, and Oak Ridge, Tennessee, on the Clinch River, in addition to a trained cadre of nuclear engineers.

The first Atomic Energy Act, the McMahon Bill, became law in August 1946. It established the Atomic Energy Commission (AEC) and took control of nuclear power from the military and gave it to a civilian agency. In 1947, U.S. atomic bomb tests on Bikini Atoll showed that a fleet of surface ships could be destroyed by one bomb. Then in 1949, Russia exploded its first atomic bomb, ending the brief American monopoly.

Captain Hyman Rickover, son of a poor Jewish immigrant from Poland, became the czar of the nuclear reactor-powered Navy and the first practical reactors. Rickover received his authority and line of responsibility primarily from Congress. The conventional admirals argued against the project, so in 1953, a major cancellation of the propulsion program came as part of the new administration's spending cut. Rickover, a dedicated leader, maintained government support of his project in the face of strong opposition by turning his efforts toward civilian electric power reactors.

The first atomic powered submarine, Nautilus, was launched in 1954, and soon proved it could go farther and faster than conventional submarines. The first nuclear electric power station began operating in December 1957 at Shippingport,

Pennsylvania, built by Westinghouse Electric Company. The Navy's Nuclear Propulsion Program supported both the Bettis Atomic Laboratory and the Shippingport reactor. Duquesne Light Company used the electricity produced, maintained the reactor, and invested about \$30 million in its construction. The Westinghouse Pressurized Water Reactor (PWR) at Shippingport was cooled by ordinary water at very high pressures, 1,500 atmospheres, and the water also acted as the moderator to slow down the neutrons.

About the same time, the General Electric (GE) Company took over the Hanford Atomic Works on the condition that the AEC would build and fund Knolls Atomic Power Laboratory near GE's research laboratory in Schenectady, New York. This helped GE to become competitive with Westinghouse. GE built one submarine reactor, a complex sodium rather than a water-cooled system. GE pressed the development of the Boiling Water Reactor (BWR) in which the cooling water boils rather than becoming pressurized, eliminating high pressure vessels and piping. The steam produced was used to drive the generators directly instead of going through an intermediate heat exchanger. The BWR was the simplest and least expensive power reactor ever produced.

In 1959, GE's first commercial BWR, Dresden I, produced 200 megawatts for Chicago's Commonwealth Edison Company. Through the early 1950's the American electric utilities were reluctant to use nuclear reactors. However, the U.S. Government initiated the "Atoms for Peace" program which generated such enthusiasm, particularly in Europe, that American utilities soon joined the effort.

In 1964, a major precedent was established by GE's BWR at Oyster Creek, New Jersey, built for the Jersey Central Power and Light Company. This was the first economically competitive nuclear reactor built with private funds. It is significant that GE built this plant as a turnkey contract (a total package deal) in which GE took all the financial risks. Westinghouse matched GE's sales advantage at Oyster Creek by also offering fixed-priced, turnkey contracts to all utilities.

Eventually, industry has to step up to the risks of new technology and in the case of nuclear reactors, Westinghouse and GE did so. Of course, they did this only after the U.S. Government spent about \$6.2 billion and 22 years on the initial developments. Westinghouse and GE were viewed as heroes for taking over the great technical and financial risks which were involved. At this point additional companies entered the market. Babcock and Wilcox Company and Combustion Engineering were attracted by the large and growing market.

Not enough research was done on the handling of nuclear materials in the rush to build economical electrical generators with nuclear reactors. At a Salzburg, Austria, meeting of the industry in 1977, Alvin Weinberg, famous head of Oak Ridge National Laboratories for many years, bared his personal fears about the future of nuclear reactors. He was concerned about core meltdown accidents and the accumulation of nuclear wastes. The latter problem would increase radiation hazards and the proliferation of bomb-grade plutonium. Then, at Three Mile Island (TMI) near Middletown and Harrisburg, Pennsylvania, on March 28, 1979, a PWR built by Babcock and Wilcox Company experienced a simple loss of coolant that caused a hiatus in nuclear power developments. There was no meltdown, no explosion, no loss of life. A relief valve stuck open and released 32,000 gallons of slightly radioactive coolant waste into the containment vessel. The radiation that escaped was deemed to be safe by the Nuclear Regulatory Commission (NRC). Had the operator realized that the valve was stuck and closed a second valve, the accident would have been minor.

Instead, TMI became the media event of the year, changing the publics' psychological response to nuclear power plants. The cost to clean it up was estimated to be at least \$1 billion. The President's Commission which studied the accident found that operators had not been properly trained, emergency procedures were inadequate, and communications between builder and operator were poor. The question was raised, "Did the government spend the taxpayer's money in the right places: safety of operation, control of accidents, fail-safe designs, knowledge of radioactive release, clean-up and decontamination procedures?" Two hundred thirty-nine nuclear plants around the world are now operating and producing electrical energy from nuclear reactors. One hundred sixty-three are being built, and another 172 are planned. Obviously, more questions will have to be answered and development continued to understand the problems, but the clock cannot be turned back.

### VIII. COMMUNICATIONS SATELLITES

Communications satellites represent the outstanding example in history of the most rapid and complete transfer of technology from governmental to commercial support. It represented the immediate welding together of spacecraft launch and electronics technology, directly replacing and pushing out an older, more expensive technology. At the same time, it was being pulled by a hungry market, and inter-continental and long-distance telephony and television, which was ready to pay the cost and take the risks without further governmental incentive. The history is brief and simple [5].

Explorer I, the first free-world satellite, launched on January 31, 1958, by the Von Braun team, established launch capability. At that time, the Western Electric Company was involved in laying transoceanic cables and repeaters for hard-wired telephony. Explorer VI, launched 18 months later on August 7, 1959, carried the first television from space, and the world caught the vision.

Syncom II, launched July 26, 1963, for Comsat Corporation, was the first active television repeater placed into a stationary geosynchronous orbit. Intelsat I (Earlybird), launched April 6, 1965, was the first to carry 240 two-way voice circuits or one color TV channel. Intelsat III (F-2), launched December 18, 1968, was the first to carry 1,200 two-way voice circuits or four color television channels. A string of Intelsat IV's (such as F-2, launched January 26, 1971, which carried 4,000 two-way voice circuits or twelve color TV channels) was placed around the world, and communications satellites became economically profitable.

NASA's Applications Technology Satellite (ATS-6), launched May 30, 1974, was the last experimental communications satellite. It carried 20 experiments for the Corporation for Public Broadcasting, Department of Health, Education and Welfare, and Commerce Department, and when these were completed, was moved over India for use by that nation. It carried a 30-foot diameter parabolic antenna for broadcasting a signal in the 4-6 gigahertz range. No further demonstrations, prototypes, or examples were needed. By 1977, the industry was ready to fill the available spaces in geosynchronous orbit (one every 4 degrees around the equator), and asked for no further incentives from NASA. Although there is continuing research going on (higher frequencies, longer life, direct broadcast television), the industry moved from birth to self-sustaining maturity in 19 years. It is rivaled only by the transistorized integrated circuit for its rate of maturation. The formation of Communications Satellite Corporation (Comsat), as America's participant in Intelsat, was a major step in moving from government to private support.

## IX. HISTORICAL SUMMARY

The clear indication from examining these case histories of governmental support for new technology developments is that they paid back the investment, handsomely. Some required governmental support for initial research (early naval and aircraft technology), some for engineering prototypes until commercial feasibility was demonstrated (jet aircraft and nuclear reactors), and some for support of gigantic construction projects using developed technology (canals and railroads). These histories are summarized in the Appendix which shows the relative size of the project in estimated man-years of effort rather than funding. This normalizes the ever-changing value of money but does not correct for human productivity. In every case but the earliest one, the nation initiating the support reaped handsome results after some time passed, so that the nationality of the beneficiaries was well defined, even when the individuals could not be identified. The expansion of new territories, markets (both domestic and international), businesses, and jobs occurred far beyond the dreams of the perpetrators. Also, in every case, it is apparent that there was a hard-driving, enthusiastic, charismatic personality who pressed the case for the project in the face of many detractors and opponents, who saw only difficulties and costs. The question now before us is, "How will the current American space effort be exploited commercially and what financial procedures will be employed to facilitate the transition from government to private initiative?"

## X. NASA ACTIVITIES LEADING TO COMMERCIAL OPPORTUNITIES IN SPACE - 1983

Almost from its beginning in 1958, NASA had an applications office to facilitate a rapid transfer of technology from its research, developmental prototypes, and other specific programs to industry. NASA has identified Materials Processing as a commercial opportunity in space. We will not include here the natural diffusion of information and practical ideas from other programs, such as manned exploration and planetary sciences, which have nurtured electronics, materials, and propulsion technology on Earth to accomplish their own missions. Also, we will not discuss Earth and ocean observations for meteorological, agricultural, geological, and nautical applications, because those applications are not readily commercialized, even though they are very valuable. We will discuss some potential Materials Processing in Space (MPS) areas, which have been totally government funded until recently.

The ultimate goal of the current Materials Processing in Space Program is to use space to perform low-g research to improve process technology or to develop new products on Earth, and to prepare research quantities of material in low-g which serve as examples for comparison with current Earth-based technologies. Materials processing on Earth is a very mature technology. Therefore, it is recognized that it will be necessary for NASA to provide the impetus for demonstrating to potential industrial users that they can do more with their process by conducting experiments in space than they can do on Earth. This is accomplished by working closely with industries to the point of understanding their problems sufficiently to identify areas in which materials science and engineering in low-g can best be utilized. It is not realistic to expect major commitments from industry alone until NASA has completed a sequence of space flight opportunities and has been given a chance to demonstrate the potential that space offers. Also, ways must be found to select experiments for flight, protect the proprietary rights of the customer, reduce the lead time, and lower the costs of conducting experiments in order to attract the private industrialist.

An important first step is the establishment of joint projects, with varying levels of involvement with industrial users to assist them in exploring areas where MPS can be utilized to meet their needs. These joint projects are envisioned to be "constructive partnerships" between NASA and industrial firms wherein the parties are equals who have common objectives. NASA is working to provide clarification of patent protection rights, proprietary rights, liabilities, leasing policy, and pricing. NASA believes it can provide a simpler interface to the private sector, develop a better understanding of the incentives needed to elicit private initiatives, and stimulate the inventive genius and entrepreneurial spirit in this country.

Joint projects between industry and NASA are not government procurements but rather agreements to cooperate in a defined area with specific tasks to be accomplished by each party [6]. They are expected to evolve with increasing interest and responsibility on the part of the industrial partner. Commercial MPS has three levels of working relationships to provide for incremental increase in commitment by the parties involved. They are:

- o Technical Exchange Agreement (TEA) which involves cooperation in analysis of data and specimens from ongoing NASA research.
- o Industrial Guest Investigator (IGI) which involves collaboration with a NASA-sponsored Principal Investigator (PI) of a flight experiment.
- o Joint Endeavor Agreement (JEA) which is an investment by private enterprise sharing in the cost and risk of an early space venture where NASA provides launch and space flight services.

#### A. Electrophoresis

The best examples of commercial opportunities and of government to industry interfaces are given by the current JEA's between NASA and industry. The first is the McDonnell-Douglas Corporation (MDAC) purification process for pharmaceutical products employing an open-channel, continuous flow electrophoresis system which is not useful for production on Earth because of the overwhelming effects of thermal convection. MDAC is also an example of a corporation that is well experienced in doing business with NASA at all levels.

Electrophoresis has long been a valuable analytical technique for characterizing biological mixtures of proteins. Paper and gel substrates are employed to overcome sedimentation and flow due to thermal convection, but they greatly reduce the amount of product separated. Ingenious devices to obtain greater throughput and to fractionate larger molecules and biological cells were designed by Strickler and Hannig, called continuous or free-flow electrophoresis. However, these machines never filled the need for production quantities of fractionated material because their resolution was defeated by mixing due to thermal convection.

In the late 1960's several people suggested the possibility of using the low-g conditions of space flight to overcome convection and sedimentation, thereby providing a high-resolution/full-flow device. The first simple NASA demonstration experiment was made on Apollo 14 on the way home from the moon [7]. Improved measurements were made on subsequent flights, and NASA made a major step forward with a live cell separation on Apollo-Soyuz (1975) which attracted much attention [3]. MDAC joined the search for a bioprocessing purification/separation method in

1977 with its own Electrophoresis Operations in Space (EOS) Program and later signed a JEA with NASA. MDAC designed an improved continuous flow device (the NASA experiments were batch or static devices) with wider flow channels than those used on Earth to obtain greater throughput. It is being tested on the Space Shuttle (STS-6, 7, 8, and 11), first with known calibration samples and then with practical biological materials. These were supplied by the Ortho Pharmaceuticals Division of Johnson and Johnson Corporation by agreement with MDAC for the testing, packaging, and marketing of certain products. According to James Rose, EOS manager for MDAC, the early flight experiments separated 700 times more material than is possible on Earth with the same type of equipment. This is only a research device, and improved, scaled-up equipment is expected to follow, including a 24-chamber production prototype in 1985. MDAC expects this to be the first true manufacturing facility in space, and NASA is providing flight opportunities and integration effort to assist in the development.

#### B. Gallium Arsenide Crystal Growth

The second JEA is the Microgravity Research Associates (MRA) process for growing gallium arsenide crystals in space. Gallium arsenide is one of the most important semiconductors identified for device fabrication; it is to be grown by an electroepitaxial process in low-g to reduce defects by stabilizing the system against convection. MRA is an example of a new, small business formed specifically to develop a new, risky, high technology product.

Single crystals have been desired for many uses such as electric power rectifiers; electronic, piezoelectric, and electrooptical elements; and integrated circuits because of their improved properties over polycrystalline materials. Of paramount importance in any crystal growth system is the control of the growth interface. Compositional and/or thermal fluctuations in the fluid phase (whether it be melt, solution, or vapor) can give rise to inhomogeneities or defects in the growing of crystals. Since unstable thermal gradients are virtually impossible to avoid in any growth system, some convective stirring will almost always be present in Earth-bound techniques. Such convective stirring is generally thought to be detrimental to the control of the growth process. NASA has sponsored many crystal growth experiments in space on Skylab (1973) and Apollo-Soyuz (1975) using melt, solution, and vapor growth techniques. However, the specific electroepitaxial method proposed by MRA represents a new technology.

In the electroepitaxial growth process an initial single crystal is placed in contact with a liquid phase solution, which, in turn, is in contact with polycrystalline material [9]. The passage of an electric current through the three portions results in deposition onto the single crystal in the desired crystalline orientation with a net increase in its bulk. Migration to the growth surface is controlled, primarily, by electric current in the absence of thermal convective flows, and therefore, the process is expected to provide crystals with improved properties. Ground-based laboratory experiments have been going on for several years, so the first goal is to build an apparatus for space flight that will provide crystals for comparison with the Earth-bound counterparts. Again, NASA provides integration, launch, and flight opportunities.

#### C. Mercuric Iodide Crystal Growth

Mercuric iodide ( $HgI_2$ ) crystals, although now the subject of a commercial agreement, have elicited much interest. They are the focus of a NASA-sponsored

experiment on Spacelab 3 and a European Space Agency (ESA) sponsored experiment on Spacelab 1. A vapor transport crystal growth process was accomplished on Skylab and Apollo-Soyuz where anomalously high transport rates were observed and at least one large, perfect crystal was obtained. It now has been demonstrated in the laboratory that vapor growth on Earth is much more complex than previously thought, and that low-g conditions cannot be approximated by low pressure on Earth. Also, it is not simply a matter of eliminating convection in space and enjoying purely diffusion-driven transport. More low-g experiments are needed and planned for this technique which has not been very useful on Earth but has promise in low-g conditions [10].

Mercuric iodide single crystals are highly desirable in the nuclear industry as sensitive gamma-ray energy dispersive analyzers for medical research and surveillance. These crystals are not readily available because they are difficult to grow on Earth with the needed perfection.

Mercury is dense, highly volatile, and toxic. The crystals that are used must be cooled to very low temperatures, which makes nuclear detectors very cumbersome, where  $HgI_2$  will operate without cooling. Techniques are being developed by a nuclear instrument supplier, EG&G Corporation, to grow mercuric iodide crystals by the vapor condensation method in space. These crystals used as sensors in surveillance equipment are expected to greatly increase the sensitivity and resolution of nuclear detectors.

#### D. Mercury Cadmium Telluride

Mercury cadmium telluride ( $HgCdTe$ ) is a very useful infrared detector largely because of high sensitivity at room temperature and the fact that it can be tuned to detect at specific frequencies such as those emitted by infrared lasers. It is useful in surveillance, energy, and astronomy fields. Currently, it is difficult to grow  $HgCdTe$  as a controlled single crystal because it solidifies into many grains. It is called a pseudobinary system because it forms mercury telluride and cadmium telluride. Binary systems such as this are unstable during growth from the melt on Earth due to thermal, density, and solutal gradients. Flight experiments are being planned in which these gravitational-induced instabilities will be eliminated. Specially controlled crystal growing furnaces are being built for automatic control during the flights of the Space Shuttle. Several companies have been working with Dr. Sandor Lehoczky of NASA on this problem; one which has had a continuing interest is Honeywell. Langley Research Center has developed a flight experiment on lead tin telluride which has a similar (but opposite) instability problem.

#### E. Monodisperse Latex Particles

For many years, the Dow Chemical Company has sold monodisperse latex particles (all one size) of up to 2 microns to calibrate instruments, to measure the porosity of biological filters/membranes, and as a drug carrier to specific regions of the body in medical research [11]. There is a need for larger sizes which has been expressed by the National Bureau of Standards and others. However, the polymerization process of the polystyrene particles is such that larger particles tend to sediment, and increased agitation only leads to unwanted coagulation. The kinetics of the process are complex involving reactions between seed particles, monomer, initiator, emulsifier, inhibitor, agitation or shear rate, temperature, and time. Dr. John W. Vanderhoff of the Sinclair Laboratories at Lehigh University is the recognized leader in this field, and he proposed a series of flight experiments to

take advantage of low-g. The initial experiments have now been made on Space Shuttle flights STS-3, 4, 6, and 7, with good success in producing small research quantities of particles up to 18 microns, as planned. Further experiments to obtain even larger particles and larger quantities are planned, but as yet, no commercial business plan has been proposed to NASA.

#### F. Experimental Grey Nodular Iron

It has been suggested that low-g experiments with cast iron offer an excellent opportunity to study the effects of convection and sedimentation on alloy solidification [12]. During the solidification of hypereutectic irons, density differentials between light graphite material floating in heavier liquid could be expected to cause gravity-driven segregation. Thus, it was postulated that gravity levels during solidification would have a significant effect on growth, macrostructural heterogeneity, and, particularly, the size and shape of graphite in cast iron.

In June 1981, NASA made a Technical Exchange Agreement (TEA) with John Deere and Company to collaborate in a series of low-g solidification experiments of commercial cast iron. The TEA agreement stated that during this study particular attention should be paid to finding the effects of low-g on graphite nucleation and growth. It caught the attention of many people in the iron and steel industry.

Samples solidified in low-g are being compared to control samples solidified at 1-g to determine the role that gravity plays in terrestrial cast iron solidification. If gravity has a significant influence on cast iron, this knowledge might be applied to commercial production. The point of this TEA was very different from the usual idea of making a unique product in space. Rather, it points to the use of low-g experiments to learn more about a large industry on Earth (cast iron) where even a small improvement in procedures or properties is very valuable. So far, all flight experimentation has involved short runs in aircraft (KC-135 and F-104) flying parabolas to attain low-g for up to 50 seconds. Obviously, longer times are needed on the Space Shuttle, and furnaces with better controls are required.

#### G. Experimental Coal to Coke Transformation

In the same manner in which the nodular cast iron experiment could lead to new understanding of the effect of microstructure on properties, it was proposed that the coal to coke transition might be elucidated by low-g experiments. Dr. Nicholas Franco, supervisor of basic studies at the Bethlehem Steel Corporation, suggested that little is known about the mechanisms by which coal transforms into coke as it passes through the plastic phase. Yet the microstructure formed controls the strength and, therefore, the quality of the coke for making steel. Earth-bound experiments are limited in their ability to produce different microstructures. It was suggested that a coking experiment in low-g might provide a sample with more spherical particles due to the predominance of surface tension over gravitational forces. This would lead to a more scientific way to select metallurgical-grade coal for the coking process based on microstructure. There has not yet been an opportunity to pursue this experiment.

#### H. Isoelectric Focusing of Hormones

Isoelectric focusing is a very useful variant of electrophoresis in which the separation is carried out in a pH gradient [13]. Proteins migrate to focus to the pH region corresponding to their isoelectric point where they stop moving due to the

zero charge at that point. The isoelectric point is a very specific property of a protein, and the technique can resolve particles differing by only 0.01 pH units. Dr. Milan Bier of the University of Arizona, a leading expert in the field, built a Recycling Isoelectric Focusing (RIEF) device which, like the continuous flow electrophoresis device, can now purify large production quantities of materials. It is an excellent complementary tool to the MDAC continuous electrophoresis device.

One of the Earth-bound limitations of the RIEF apparatus is that the pH zones are separated by membranes to reduce convection and maintain the charge gradient; the proteins must migrate through them and they become clogged. A similar apparatus in space could maintain the pH gradient without the membranes. A preliminary experiment to determine the effects of electroosmotic flow on this system is being prepared for the Space Shuttle on STS-11. It is expected that if the RIEF operation is sufficiently enhanced in low-g, it eventually will find application in the purification of several specific hormones.

#### SUMMARY

The foregoing list of examples of possible commercial ventures in space, taking advantage of low-g, is far from comprehensive. There are still other pharmaceutical separation techniques being explored, other valuable single crystals that need specialized conditions for controlled growth, and other metallurgical processes which are being researched. Much experimentation needs to be done such as preliminary ground-based research, where only fleeting moments of low-g (free fall) time can be attained, and in Space Shuttle or continuous Space Station experiments. Past work has been inhibited because of the high cost of flight apparatus and the limited number of flight opportunities. These limitations will change and entrepreneurs will be encouraged to support flight experiments. Generally, NASA is prepared to provide integration services, launch and flight opportunities, and allow for proprietary and patent rights to benefit the other party. If the experimental phase is successful, the entrepreneur would be expected to pay for future commercialized flights. As in all the case histories discussed earlier, it is believed that the government will continue to support and encourage the new technology. It has done so many times in the past and reaped great benefits for the nation in due time. To get public support for the early developmental phase, each project filled a particular need at a particular time. This study has shown that the needed support has been attained in many ways in the past when there was an enthusiastic proponent willing to press the issue to its conclusion even in the face of competition and opposition. That kind of advocacy will work for materials processing in space.

APPENDIX

SUMMARY OF NEW TECHNOLOGY

<u>GOVERNMENT-SPONSORED DEVELOPMENT</u>	<u>PERIOD</u>	<u>ACCUMULATED COST (MAN-YEARS)</u>	<u>LEADER</u>	<u>ATTRIBUTED RESULTS</u>	<u>PRIMARY METHOD OF SUPPORT</u>
PORTUGUESE NAVAL TECHNOLOGY	1430-1580	4,500	PRINCE HENRY	DISCOVERY OF AMERICA AND ALL OF AFRICA	IN-HOUSE
ENGLISH NAVAL TECHNOLOGY	1675-1890	25,000	KING CHARLES II	SUPREMACY OF THE SEAS	IN-HOUSE
ERIE CANAL	1817-1825	7,000	DEWITT CLINTON	OPENING THE MID-WEST BEYOND THE APPALACHIANS	DIRECT SUBSIDY
RAILROADS, INTER-CONTINENTAL	1865-1890	90,000	GRANVILLE DODGE LELAND STANFORD	OPENING OF THE FAR WEST, WHEAT AND CORN BELTS	LOANS AND LAND
AMERICAN AIRCRAFT TECHNOLOGY	1920-1940 1941-1958	15,000 200,000	JOE AMES GEORGE LEWIS	AIRCRAFT SUPREMACY	IN-HOUSE AND CONTRACTED
NUCLEAR REACTOR TECHNOLOGY	1945-1979	150,000	HYMAN RICKOVER	NUCLEAR SUPREMACY	IN-HOUSE AND CONTRACTED
AMERICAN SPACE TECHNOLOGY	1958-1972	300,000	WERNER von BRAUN	SPACE SUPREMACY	IN-HOUSE AND CONTRACTED
COMMUNICATIONS SATELLITES	1959-1977	20,000	ARTHUR CLARKE BERT EDELSON	COMMUNICATIONS, TV	CONTRACTED

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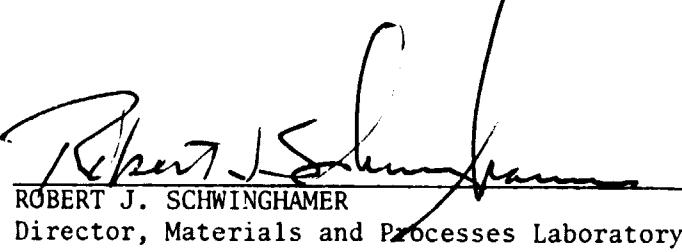
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## APPROVAL

# POTENTIAL MEANS OF SUPPORT FOR MATERIALS PROCESSING IN SPACE A HISTORY OF GOVERNMENT SUPPORT FOR NEW TECHNOLOGY

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The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.



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